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TESTING THE FERTILITY OF ALBERTA SOILS BY THE NEUBAUER AND LEMMERMANN METHODS

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TABLE OF CONTENTS

Page

I. Necessity of applying fertilizers in Alberta -------- 1

II. The soils of Alberta and their content of plant food- 2

III. Methods for determining the plant food requirements of soils -- 4

  1. Field experiment ------------------------------ 5

  2. Laboratory methods ---------------------------- 6

    a. Chemical methods ------------------ 6

    b. Biological methods ---------------- 9

    c. Combined biological and chemical method ---------------------------- 10

IV. Methods for determining the plant food requirement of soils previously used in Alberta ------------------- 11

V. Experimental results -------------------------------- 11

  1. The Neubauer method -------------------------- 11

    a. Results from Neubauer experiments and their individual discussion --- 16

    b. General discussion of Neubauer results ---------------------------- 34

  2. The Lemmermann method ---------------------- 40

    a. Results from Lemmermann experiments 41

    b. Discussion of Lemmermann results -- 41

VI. General discussion --------------------------------- 44

TABLE OF CONTENTS (Continued)

Page

1. Limitations of predicting the relation of soil phosphorus to crop plants -------- 44

2. Comarison of field experiments with Neubauer and Lemmermann determinations -- 48

VII. Summary -- 50

Acknowledgment -- 53

References -- 54

TESTING THE FERTILITY OF ALBERTA SOILS BY THE NEUBAUER AND LEMMERMANN METHODS

Helmut Kohnke

NECESSITY OF APPLYING FERTILIZERS IN ALBERTA

It is only during the past several years that commercial fertilizers have been used somewhat extensively in Alberta. The most fertile parts of the province had been settled first and it was assumed that the comparatively low rainfall would be the limiting factor of crop production rather than plant nutrients, which were believed to be abundant in most of the cultivated soils of Alberta.

Recent field experiments (5), however, have shown that a great many soils give decided response to the application of different fertilizers. This may be due to the many crops that have been taken from the land, as well as to the fact that recently the poorer soils have also been brought under cultivation.

THE SOILS OF ALBERTA AND THEIR CONTENT OF PLANT FOOD

The three main soil belts of Alberta are the brown prairie soil, the black parkland soil, and the grey wooded soil. Originally of a similar material these soils owe their development to the climatic conditions of the regions where they occur.

The brown prairie soil belt has a semi-arid climate. Low precipitation and high evaporation due to high summer temperatures and drying winds tend to accumulate water soluble salts near the surface. Leaching of plant food into the subsoil does not take place. Owing to the comparative dryness of this district the native vegetation consists mainly of short grasses, which do not add very much organic matter to the soil. The hot dry climate of the southern part of the province tends to speed up the decomposition of plant remains. The result is the relatively low humus content of the typical brown prairie soils.

The black parkland soil belt has a somewhat higher precipitation, lower evaporation and a shorter summer. These three facts result in a more moist climate. The grasses growing naturally in this district are tall and the bushes found here assist in breaking the power of drying winds. There is much organic matter to be decomposed, and this decomposition is comparatively slow so that it is balanced by the reproduction of organic matter by the plants, resulting

in a high humus content of the soil. The Alberta black loams belong to the most fertile soils in the world.

Coming farther north or closer to the Rocky Mountains we find the grey wooded soil. Although on the whole the precipitation is not appreciably higher than in the parkland belt, leaching takes place here due to a shorter summer, less evaporation, the wooded characters of the vegetation, and possibly other factors. The more soluble parts of the soil are carried down by the water into the subsoil, leaving behind the parts that are less available to plant roots, thus resulting in a less fertile condition. The decomposition products of the vegetation are also rapidly leached out by the water, so that the soil is low in organic matter, and consequently low both in water holding capacity and nitrogen.

The productive power of the black soil is the highest, followed by the brown soil, the grey wooded soil being the least fertile. There exist of course no definite boundaries between these soil belts, the changes being rather gradual.

In general it can be said that the black soils contain enough nitrogen to produce any crop, while in many cases nitrogen will be the limiting factor on grey wooded soils. The brown soils take an intermediate position in this respect. However, even in the black soils soluble or available nitrogen may sometimes be a limiting factor.

As to the potassium requirements of Alberta soils nothing definite can be said since the number of field exper-

iments with potassium has hitherto been very small. It seems, however, justifiable to assume that in general the brown prairie soils are well supplied with available potassium. This may be the case because potassium, which, under humid conditions, is much more subject to leaching than phosphorus, is not removed from the soil since no leaching occurs. On the other hand it is possible that the catalytic action of potassium is substituted to a certain extent by the sunshine that is abundant in this province, particularly in the south (20). However, the experiments reported later in this paper seem to indicate that many black and grey soils of central and northern Alberta are low in available potassium, and that a careful study of this question is advisable.

The most detailed investigations have been made with phosphorus. Field experiments (5,25) have shown that phosphorus is the limiting factor of crop production in many soils of Alberta. A definite relation, however, of the amount of available phosphorus to the different soils could not be found. On the contrary both soils rich and deficient in available phosphorus are found in the brown, black and grey belts. No connection between soil type and phosphorus supply seems to exist.

METHODS FOR DETERMINING THE PLANT FOOD REQUIREMENTS OF SOILS

The above mentioned experiments (5,25) have proved

that it would be profitable for many farmers to apply phosphatic fertilizers. Nitrogen deficiency generally can be noticed by observing the crop, whereas this is not possible in the case of phosphorus. Naturally it would be of great advantage if we could predict whether a soil would give response to phosphate fertilization or not. The farmer cannot affort to spend money for cultivation methods if he is not reasonably certain to get returns.

Field Experiment

One way of telling the food requirements of crop plants is the field experiment. If the field experiment is conducted in a scientific and careful manner and no special difficulties arise it is, up to date, the most dependable method of determining the manurial condition of the soil. But there are serious reasons for us to look for other methods.

First of all the field experiment takes a whole growing season and we get our data a year too late. For the crop has taken a certain amount of plant food from the soil, and we do not know how the soil will react next year. Another drawback is the different influence of the weather upon the yield. It is a well known fact that the weather is the most important single factor limiting crop yield. The influence nitrogen, potassium, phosphorus and calcium exercise upon the crop differs very much with the season. Consequently we have

to carry out experiments for a number of years in a given locality before we can have a clear picture of the necessity of fertilizing with the different plant foods. And even then we have to repeat the field experiment almost every year because we can calculate only roughly how much of the nutrients has been taken away by the crop, leached out, rendered unavailable, or on the other hand has been added in the form of manure or made available in the soil.

These considerations show us that the field experiment is also a very expensive method, and it would be very desirable to find a shorter and cheaper device that would at the same time be independant of the weather.

Laboratory Methods

Various chemical, biological and combined chemical and biological methods have been proposed for the purpose of determining available plant food in the soil.

Chemical Methods: The determination of the total soils' phosphorus is no indication at all of the available phosphorus. Soils of approximately the same phosphorus content showed entirely different reactions towards application of phosphatic fertilizers. Only 0.5-1% of the total phosphorus of the upper 8 inches of the soils under discussion are found in a wheat crop of 40 bushels per acre. Soil extracts made

with strong acids give also very high figures, but direct relationships cannot necessarily be found between the figures so obtained and field results.

The use of solvents that are more similar in solvent action to the natural soil solution around the roots has therefore been suggested. The roots give off carbon dioxide, consequently it is assumed that the soil solution around the roots is more or less saturated with carbonic acid.

Water saturated with carbon dioxide has been used (11). It seems, however, to be difficult to keep the solution at the same concentration. To avoid this difficulty weak solutions of HCl, HNO_3, H_2SO_4 (22) and citric acid have been taken instead. In addition to the above acids, Wheeting (23) used 10% NH_4Cl solution and steam as the solvent. But all these methods are at best of local value. We can not be surprised about this at all. These methods are based on the assumption that the solvent action of plant roots upon the soil is comparable to that of water saturated with carbon dioxide.

The amounts of carbon dioxide excreted by the roots of the various crops is very different and if the above mentioned assumption were correct, one should expect that those plants giving off much carbon dioxide would exert a higher solvent action upon the soil, and would be able to take more nutrients from a given soil than plants that give off little carbon dioxide. No such relationship, however, was found in the experiment conducted by Parker in Wisconsin (18). On the contrary, buckwheat, a plant whose roots excrete

the least amount of carbon dioxide of several plants under investigation, has the greatest ability of absorbing phosphorus and calcium from the soil.

Although other workers found direct relationships between the quantities of CO_2 given off by the roots and the nutrients taken up (15), we believe that there are also other important agents in plant life that bring the nutrients into solution and whose effects are much more complex than that of an acid. The nature of these agents is as yet unknown. The conclusion forces itself upon us that we cannot expect any acid to show us the amount of phosphorus that a plant will be able to extract from the soil - not even an amount that would be directly proportional to it.

Many workers have simply used the solvent action of water (4,11,18,21). But while acids extract much more phosphorus from the soil than plants can take up, water extracts less than there is available to the roots (24), and the relationship between these extracts and the actual quantity of plant available phosphorus does not seem to be any fixed ratio, but varies rather under different climatic and soil conditions. Most of these methods seem to work more or less satisfactorily under the conditions for which they are developed, but frequently fail in other localities.

Lemmermann determines the relative solubility of the soil phosphorus by analyzing for both the total phosphorus and that part of it that is soluble in 1% citric acid solution. This method seems to have a rather wide range of adaptation. It

will be discussed in detail at a later point (V.2).

Biological Methods: Of the biological laboratory methods for determining phosphorus requirements of crop plants only two have been used to any extent; the Mitscherlich method and the Azotobacter test.

Mitscherlich (8) grows crop plants (preferably oats) during a whole season in crocks on differently fertilized and untreated soil and derives from the difference of the yield the manurial condition of the soil. He claims to be able to predict the fertilizer needs of the soil for several years. However, efficient this method may be it has the great disadvantage of requiring a whole summer and exceedingly large soil samples (15 kg.) for each determination. This makes it too cumbersome and too expensive for general use.

The Azotobacter test was mainly developed by Christensen (1). He mixes soil with 5% pulverized starch or 1% mannitol, adds some $CaCO_3$ and inoculates it with pure cultures of Azotobacter chroococcum. Soil producing large rapidly growing colonies of Azotobacter is said to be rich in available phosphorus. Soil not producing colonies is said to be very low in available phosphorus. Azotobacter is a bacterium with an exceptionally high phosphorus content (about 50% of the ash is P_2O_5), consequently, under otherwise favorable conditions for propagation, (carbohydrate, $CaCO_3$, moisture, temperature) the amount of available phosphorus will be the limiting factor in colony formation. Doubtlessly these

assumptions are sound, but there is no proof that the phosphorus requirements of Azotobacter and those of the higher plants run parallel. In fact, in Denmark, where this method was developed, it is no longer used to any considerable extent (8). According to a recent publication of Sackett and Stewart the Azotobacter method proved to be very satisfactory in Colorado (19). It also was tested in Alberta. No satisfactory growth of Azotobacter, however, was obtained. More recently Nicklas (16,17) has worked out another biological method for the determination of plant food in soil. To a nutrient medium lacking in the element to be tested a small amount of soil is added. This medium is inoculated with Aspergillus niger. After a few days of incubation the mycelium is weighed and conclusions as to the content of available plant food in the soil are drawn from this weight.

Combined Biological and Chemical Method: A method that may be called a combined biological and chemical method has been worked out by Neubauer (9,10,11,12,13,14). He uses the solvent power of the roots of germinating rye plants to determine the amount of available phosphorus and potassium in the soil. Experiments according to this method make up the major part of the research this thesis is based upon and will be reported at a later point (V.1.).

METHODS FOR DETERMINING THE PLANT FOOD REQUIREMENTS OF SOILS PREVIOUSLY USED IN ALBERTA

Several methods have been used in recent years with the object of determining plant available phosphorus in Alberta soils (4). Total phosphorus and water soluble phosphorus have been determined as well as phosphorus soluble in a 0.002 N H_2SO_4 solution. No close relationship, however, between the results and field experiments could be found. The results obtained from soils known to be deficient in available phosphorus were frequently much higher than the standards set in more southerly districts for soils sufficiently provided with phosphorus. Whether this is due to the difference in climate or the difference in soil type or both we do not know.

EXPERIMENTAL RESULTS

In 1931 two other methods for determining available phosphorus in soil were tried out as to their value for Alberta soils: the Neubauer method and the Lemmermann method.

The Neubauer Method

Neubauer concluded that if a great number of germinating plants grew in a small amount of soil the roots would

permeate the soil very completely and take up most of the available plant food. It would be necessary only to determine the amount of phosphorus and potassium taken up by the plants to have a fair indication of the nutrient condition of the soil.

This method is mainly based upon the assumption that germinating plants do not live as long as possible on their reserves stored in the seed but extract all they can from the medium surrounding their roots. In this respect they have a considerable greater power than older plants.

One hundred rye kernels are placed in 100 gms. of soil mixed and covered with 300 gms. of sterile glass-sand. After 18 days growth the plants are removed from the soil and their phosphorus and potassium content is determined. Parallel experiments are conducted in the same way with sterile sand alone. The difference between the phosphorus and potassium content of the plants grown in the soil and those grown in the sand gives the amount of phosphorus and potassium taken from the soil#.

According to Neubauer the temperature of the culture room has to be kept between 18 and 22° C. While during the winter this condition is easily maintained it is impossible to do so in an ordinary room during the summer. The quantity of

---

The details of the seedling method are given in Neubauer's original report of 1923 (14) and more recently in the text book on plant nutrition by Honcamp (12).

the deviation from the correct result due to too high temperature does not seem to be reported in the literature. Experiments to solve this question could not here be carried out due to lack of accomodations.

Neubauer claims that the intensity and daily duration of illumination are without influence upon the absorption of P_2O_5 and K_2O by the rye seedling as long as the culture pots are not exposed to direct sunlight. It has been proved, however, that constant illumination speeds up the absorption of nutrients. Under such conditions the maximum amount of P_2O_5 and K_2O is taken up in a shorter time. Dietz (3) made use of this fact to shorten the time required for carrying out the Neubauer analyses. By continuous illumination he reduced the period from 18 to 10 days. The main reason that Neubauer uses rye for his determinations is that rye is not very sensitive towards acid conditions of the soil so that the amount of P_2O_5 and K_2O taken up by the seedlings is not influenced to any great extent by the soil reaction. This is very important since more than half of the German soils are acid. Under such conditions the growth of wheat seedlings for instance would be decidedly hampered; the plants would take up only comparatively little nutrients.

If the rye seedlings have removed 6 or more mgm. P_2O_5 and 20 or more mgm. of K_2O from 100 gms. of soil, Neubauer assumes that the soil is well supplied with these nutrients in an available form under the conditions of average farming

in Germany.

In order to see whether these minimum requirements apply also under Alberta conditions, we have to see how Neubauer derived them. His conclusions are as follows:

The surface soil (the upper 20 cm.) of one hectare weighs approximately 3 million kg; consequently 1 mg. P_2O_5 (or K_2O) in 100 gms. of soil corresponds to 30 kg. P_2O_5 (or K_2O) in the surface soil of one hectare. A crop of 3000 kg. wheat per hectare (44 bushels per acre) contains 38 kg. P_2O_5 and 68 kg. K_2O in grain and straw. Since the roots of crop plants in the field are much farther apart than the roots of the rye seedlings in the culture pots they can take up only a part of the actually available nutrients in the soil. Naturally, this percentage varies with the crop. In the case of wheat it is 33% of the phosphorus and 15% of the potassium. The amount of nutrients necessary in available form in the soil of one hectare for the production of a crop of 3000 kg. of wheat will therefore be:

$$\frac{38 \text{ kg.} \times 100}{33} = 114 \text{ kg. } P_2O_5$$

and

$$\frac{68 \text{ kg.} \times 100}{15} = 453 \text{ kg. } K_2O.$$

Since 1 mgm. in 100 gms. of soil corresponds to 30 kg. per hectare,

4 " " " " " " " " 120 " " "

15 " " " " " " " " 450 " " "

Consequently 4 mgm. P_2O_5 and 15 mgm. K_2O in 100 gms. of soil will be the minimum requirement of available nutrients for a production of 44 bushels of wheat per acre.

The requirements of most of the other crops are higher than those of wheat.

The figures Neubauer found for average yields under German conditions are as follows: (12).

	mgm. K_2O	mgm. P_2O_5
Barley	19	5
Oats	16	4
Wheat	15	4
Rye	13	4
Red Clover	19	4
Potatoes	28	5
Sugar Beets	19	5
Mangels	29	6
Rape	15	7
Alfalfa	25	7
Meadow grass	19	4

According to Neubauer one ought to strive for a content of 20 mgm. available K_2O and 6 mgm. P_2O_5 in the soils. A certain amount of nutrients will be constantly lost by leaching or fixation into unavailable form or in other unknown ways. It is therefore desirable to have a certain surplus. In comparing the Neubauer figures with field results it will be necessary, however, to use the critical figures for the individual crops.

For the successful interpretation of the results of Neubauer determinations we have, of course, to take all the local factors into consideration. If the rotation contains mostly grain crops the figures for the minimum requirements

can be lowered, while they have to be increased where clover, beets or potatoes are frequently grown, as can be easily understood by comparing the critical figures given above for grains and root and forage crops. For a light soil that gives low yields the minimum requirements can be lower than for a fertile loam. The same applies for a dry climate compared with a moist climate. If the soil is high in organic matter its apparent specific weight will be lower than 1.5 (the figure that Neubauer used as average), consequently the minimum requirements will have to be increased correspondingly, since the calculations are based upon the weight of the surface 20 cms. of 1 hectare.

These considerations assist us in estimating the minimum requirements for Alberta soils. The factors due to which the figures should be greater than in Germany are: dryer climate, shorter frost free season, lower apparent specific weight (for black soils and peats only) greater natural fertility of the soil. Opposite factors are: lower yields, more grain in the rotation.

Seeing that there are plus and minus factors it seems to be the safest - before having enough material of our own - to assume that the minimum requirements set by Neubauer for German conditions hold also more or less for Alberta.

Results from Neubauer Experiments and Their Individual Discussion: For the Neubauer determination 42 soil samples were taken from different parts of Alberta. As far as possible fields can be lessened, while they have to be increased where a thin, beds or furrows are frequently given. We can as really understand by comparing the critical figures given above the [illegible] the roots and tubers etc.. For a light good sand soil low yields and minimum requirements can be lower than for a fertile loam. The same applies for a very intensive management with a moist climate. If the soil is high in organic matter its apparent specific weight will be lower than 1.3 [illegible] that moisture [illegible] so strongly, consequently the minimum requirements will have to be increased considerably, since the calculations are based upon the weight of the content of cum. of 1 hectare.

These considerations assist us in estimating the minimum requirements for different soils. The factors due to which the figures should be greater than in [illegible] are dry climate, shorter frost free season, lower apparent specific weight (for black, acid and peat soils) greater natural fertility of the soil. Opposite factors are: lower yields, more rain in the rotation.

Having kept always in mind that plant factors are about to be the safest - within certain limits - [illegible] we - to assume that the minimum requirements set up for the German conditions will also more or less hold for Illinois.

Regions from temperate environments and their distribution

Discussion: For the practical [illegible] of soil analyses data taken from different parts of America, as far as possible [illegible] were chosen whose response to fertilizers - particularly phosphorus - in 1931 or 1930 were known. Unfortunately only a limited number of field experiments has been carried out in Central Alberta, and therefore we have been compelled to use samples from fields whose manurial conditions we did not positively know. This doubtlessly decreased the value of our work to a certain extent.

Field data concerning potassium are particularly scarce and though the available potassium has been determined in all 42 samples, the results will merely be recorded; detailed conclusions however will not be drawn.

Table I indicates the location and the owner of the fields where the samples were taken, while Tables II-VI show the results of the Neubauer analyses and of the field experiments, thus giving an opportunity to compare both and to draw conclusions as to the reliability of the Neubauer method under Alberta conditions.

The detailed discussion of results obtained from each soil sample is given after the individual number, whereas, a summary and general discussions will be given following the tables. Soil samples 1 to 13 inclusive are black parkland soils; samples 14 to 20 inclusive are brown prairie soils; samples 21 to 31 inclusive are grey wooded soils; samples 32 to 40 are transitional wooded soils and samples 41 and 42 are other soils.

Table I. Location and type of soils analyzed.

No.	Owner	Location	Soil type
		Black Parkland Soils	
1	Geo. McLauglin	Clyde	Heavy loam
2	Southwick	Leduc	Silt loam
3		Leduc	Silt loam
4	Loewenstein	Clyde	Silt loam
5	"	Clyde	Silt loam rich garden soil
6	H. McLaughlin	Spruce Grove	Heavy loam
7	Ball	Strathcona	Loam
8	"	"	Loam
9	"	"	Loam
10	"	"	Loam
11	University	Edmonton	Clay loam
12	"	"	Clay loam
13	"	"	Clay loam
		Brown Prairie Soils	
14	C.P.R.	Brooks	Fine sandy loam
15	C. S. Noble	Cameron Ranch	Light silt loam - dry land
16	H. Mellafont	Coutts	Loam - dry land
17	Roy Anderson	Barnwell	Loam - irrigated
18	W. Volgardson	Taber	Light clay loam - irrigated
19	Experimental Station	Lethbridge	Heavy loam - irrigated
20	"	"	Silt loam - dry land
		Grey Wooded Soils	
21	W. R. Squance	Warburg	Loam
22	Johnson	Breton	Silt loam
23		Warburg	Gritty loam, virgin, only A_2 horizon
24		Warburg	Loam, virgin, only A_2 horizon
25	W. R. Squance	Warburg	Loam
26	Margerison	Fallis	Loam
27	Experimental Field	Breton	Loam
28	"	"	Loam
29	"	"	Loam
30	Deiseng	Fallis	Loam
31	Hicks	Fallis	Loam

Table I (Continued)

No.	Owner	Location	Soil type
		Transitional Wooded Soils	
32	Caspar	Fairview	Clay loam
33	"	"	Clay
34	Lassen and Villadsen	Duffield	Loam
35	"	"	Loam
36	Turnbull	Onoway	Loam
37	Roy Lent	Duffield	Light loam
38	" "	"	Loam
39	McKerral	Tofield	Loam
40	Ferguson	"	Loam
		Other Soils	
41	Rickett	Darwell	Peat
42	Loewenstein	Clyde	Sandy light clay - subsoil exposed to surface.

Black parkland soils; data given in Table II.

1. The sample was taken a year after the field experiment. In that time changes in the availability of plant nutrients are bound to occur. According to the owner, the average yield of the field in question was 41 bushels of wheat per acre, while that of the check plot is decidedly lower than that, and even the yield of the plot fertilized with superphosphate is lower than that of the rest of the field. This suggests that the experiment has been on a poor spot and that on the other parts of the field response to P_2O_5 fertilization is not likely to occur.

2. The wheat of the field experiment was badly damaged by hail. Field inspection before hail (end of July) showed great response to P_2O_5 fertilization.

3. The sample was taken about 2 miles distant from sample 2 in a field of about the same soil type. Due to different previous cultivation and cropping, entirely different amounts of available plant food were found.

4. This field has been cropped for 8 years in succession, and yielded in 1930 a small crop of wheat. A small amount of available P_2O_5 was to be expected.

5. The sample was taken from a garden which had been a pig yard until 1929 and was consequently expected to be exceedingly rich in available plant food. The very high Neubauer figures give a good picture of this condition of extreme fertility.

Table II. Field responses to fertilization and Neubauer data.

Black Parkland Soils

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treat-ment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm. K_2O	mgm. P_2O_5	
1		1930 Treatment — Yield of Wheat Check — 33.6 bu. per acre 100 lbs. treble superphosphate — 39.5 " " " Increase — 5.9 " " "	Yes	31.1	12.9	No
2	Wheat	1931 Treatment — Yield of Straw# Check — 3780 lbs. per acre 100 lbs. treble superphosphate — 4790 " " " Increase — 1010 " " "	Yes	18.8	3.9	Yes
3		No field experiment for comparison	?	12.4	12.7	---
4	Potatoes	1931 Very small yields throughout the whole experiment due to Rhizoctonia solani. Variations in yield unjustifiable by fertilizer treatment.	Expected	21.3	4.2	Yes
5	Potatoes	1931 Yields could not be ascertained as owner had dug part of the potatoes prematurely. Inspection of the hills showed very rich yield and no increase due to application of N.P.K.	No	54.2	15.8	Yes

# Due to hail damage the grain yields were only very small.

Table II (Continued)

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm.K_2O	mgm.P_2O_5	
6	Wheat	1931 Treatment — Yield of Wheat Check — 26.4 bu. per acre 50-150 lbs.treble superphosphate — 38.1 " " " Increase — 11.7 " " "	Yes	14.3	2.4	Yes
7)	Grass and clover mixture after wheat	High content of available P_2O_5 due to application of superphosphate was to be expected	No	29.5	14.2	Yes
8)			No	30.1	10.0	Yes
9)		1930 Treatment — Yield of Wheat Check — 27.7 bu. per acre 100 lbs.treble superphosphate — 27.2 " " " 86 lbs. Ammonium phosphate — 39.9 " " "	No	15.4	1.8	No
10)		No response to P_2O_5 alone. Great response to P_2O_5 + N.	No	18.4	5.0	Yes

Table II (Continued)

No.	Crop in 1931	Field Experiment		Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
					mgm.K_2O	mgm.P_2O_5	
		1931 Treatment	Yield of Wheat				
11	Wheat	Check	35.5 bu. per acre	Yes	36.3	3.3	Yes
12		100 lbs. treble superphosphate	40.6 " " "	Yes	30.9	3.7	Yes
		Increase	5.1 " " "				
13	Oats	Field experiment was not satisfactorily harvested, but vicinity to wheat plots (samples 11 and 12) and equal previous treatment indicate lack of available P_2O_5.		Yes	34.9	3.9	Yes

6. Of all superphosphate experiments with wheat this soil showed the greatest response. While wheat on the untreated part of the field looked almost dwarfed the wheat on the fertilized plots was tall and healthy and had much bigger heads.

7 & 8. While in general the soil samples have been taken from the check plots, samples 7 and 8 represent the plot that was fertilized with 100 lbs. of superphosphate per acre. The only difference between the samples is that sample 7 was taken in June and sample 8 in August. The high Neubauer figures for P_2O_5 should be expected.

9. Due to lack of information as to the exact location of the experiment of the previous year, this sample was taken outside the plots, and possibly it is a somewhat lighter soil. This and the elapse of one year may account for the discrepancy between Neubauer figure and field results.

10. The sample was taken on the check plot. 5 mgm. available P_2O_5 in 100 gms. of soil represents enough P_2O_5 for a good wheat crop.

11, 12, 13. A better stand of the P_2O_5 fertilized crops of grain could easily be seen during the summer months.

Brown prairie soils; data given in Table III.

14. The sample was exposed to the weather for several years. Since nothing grew in the soil and the available nutrients created could not be leached out of the box, an accumulation of these should be expected. This ex-

Table III. Field responses to fertilization and Neubauer data.

Brown Prairie Soils

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm. K_2O	mgm. P_2O_5	
14	---	This is a sample of soil stored out of doors in an open box for several years without anything growing on it.	No	35.5	18.0	Yes
15	Wheat	1931 Treatment — Yield of Wheat Check — 20 bu. per acre 60 lbs. treble superphosphate — 23 " " " Increase — 3 " " "	Yes	47.1	6.4	No
16	Wheat	1931 Treatment — Yield of Wheat Check — 22 bu. per acre 55 lbs. treble superphosphate — 26 " " " Increase — 4 " " "	Yes	29.6	1.4	Yes
17	Beets	1931 Beets responded to application of P_2O_5	Yes	21.3	2.8	Yes
18	Beets	1931 Treatment — Yield of Beets Check — 10 tons per acre 80 lbs. Ammonium phosphate — 13 " " " Increase — 3 " " "	Yes	24.2	2.5	Yes

Table III (Continued)

No.	Crop in 1931	Field Experiment			Field response to P_2O_5 treat-ment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
						mgm.K_2O	mgm.P_2O_5	
19	Beets	1931	Treatment	Yield of Beets	Yes	36.6	4.7	Yes
			Check	16.4 tons per acre				
			200 lbs. super phosphate	19.0 " " "				
			Increase	2.6 " " "				
20	Wheat	1931	Treatment	Yield of Wheat	Yes	30.5	4.6	Yes
			Check	8.7 bu. per acre				
			100 lbs. super phosphate	9.5 " " "				
			Increase	0.8 " " "				

pectation is verified by the Neubauer test.

15. If the technic of the field experiment has been perfect, the Neubauer result cannot be accounted for.

16, 17, 18, 19, 20. All these results confirm the value of the Neubauer method.

Grey wooded soils; data given in Table IV.

21. The fact that the experiment had been carried out a year previous to sampling may also in this case account for the disagreement between field result and Neubauer figure. The increase of 3.1 bushels per acre is of course also not very significant and may have been due merely to soil variations or unrepresentative sampling of the crop.

22. Field experiments in 1929 with superphosphate applied to wheat and oats showed that the field, from which this sample was taken, was deficient in available phosphorus. Since the field had been cropped also in 1930 it was to be expected that this deficiency (possibly even more pronounced) would still exist in 1931 when the sample was taken. The Neubauer figure for P_2O_5 confirms this assumption very well.

23, 24. The samples have been taken from the leached horizon of the wooded soil in order to get some idea of the agricultural value of podsolized soil. P_2O_5 seems to be present in fair amounts. Available potassium, however, is very low. This corresponds with the common knowledge that potassium is more readily leached out of soil than phosphorus.

Table IV. Field responses to fertilization and Neubauer data

Grey Wooded Soils

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treat-ment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm.K_2O	mgm.P_2O_5	
21	---	1930 Treatment — Yield of Wheat Manure — 21.5 bu. per acre Manure + 100 lbs. treble superphos. — 24.6 " " " Increase — 3.1 " " "	Yes	25.8	7.7	No
22	---	In 1929 grain showed decided responses to superphosphate treatment	Yes	10.9	3.8	Yes
23	---	Virgin land. A_2 horizon only	---	8.6	6.9	---
24	---	Virgin land. A_2 horizon only	---	7.6	7.8	---
25	Potatoes	Potatoes of fertilizer experiment with P.K.N. were drowned by rain. No results could be obtained	?	13.5	8.2	---
26	Wheat	1931 Treatment — Yield of Wheat Check — 12.1 bu. per acre 100 lbs. super phosphate — 20.1 " " " Increase — 8.0 " " "	Yes	16.1	4.0	Yes

Table IV. (Continued)

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm.K_2O	mgm.P_2O_5	
27	Several	On the Breton experimental field alfalfa and clover showed decided responses to P_2O_5 fertilization. Grain showed only very slight responses.		17.0	6.8	Yes
28	Wheat	Wheat hailed out	?	17.2	3.3	No
29	Sweet clover	1931 Treatment — Yield of Hay Check — 1922 lbs. per acre 100 lbs. super phosphate — 4055 " " " Increase — 2133 " " "	Yes	17.7	6.4	Yes
30	Altaswede and Alsike clovers	1931 Treatment — Yield of Hay Check — 1578 lbs. per acre 100 lbs. treble superphosphate — 3237 " " " Increase — 1659 " " "	Yes	8.8	4.3	Yes
31	Clover mixture	Fertilizer experiment was not harvested	?	20.5	15.0	---

26. This field showed responses to P_2O_5 both in 1930 and 1931. The low Neubauer figure is consequently entirely justified.

27, 28, 29. Since alfalfa and sweet clover showed response to P_2O_5 fertilization whereas wheat and barley did not, the Neubauer result should be between the critical figures for both these groups of crops; 6.8 and 6.4 are such intermediate figures; 3.3 is unaccounted for.

30. The high response of the clover to P_2O_5 fertilization is well in agreement with the low Neubauer figure.

31. The experiment was in a very weedy field. In July no differences in the stand of the clover could be detected.

Transitional wooded soils; data given in Table V.

32, 33. The samples were sent from the Peace River district. No field experiment was carried out, but the high yield indicates that there was no serious deficiency of any plant food. The Neubauer figures indicate that there is sufficient P_2O_5 in both soils for a good wheat crop. Sample 33 is taken from a slough while sample 32 represents the higher land surrounding it. 33 may be expected to be naturally richer in plant food as the runoff water of the surrounding land is drained into the slough and the soil is heavier. In

Table V. Field responses to fertilization and Neubauer data.

Transitional Wooded Soils

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm. K_2O	mgm. P_2O_5	
32	Wheat	(No field experiment	No	40.4	7.3	Yes
33	"	(1931 yield was about 35 bu. per acre	No	43.4	14.5	Yes
34	Alfalfa	A better growth of newly seeded alfalfa could be noticed on plots fertilized with 200 and 300 lbs. of treble superphosphate and a slight increase in yield was found by the owners.	Yes	21.8	10.1	No
35	Barley	No significant difference could be seen between P_2O_5 treated and check plots. Experiment was not weighed	?	22.0	6.9	Yes
36	Barley	In 1930 grain did not show any response to application of superphosphate Barley did not indicate any residual effect of superphosphate	No	19.0	7.2	Yes

Table V (Continued)

No.	Crop in 1931	Field Experiment	Field response to P_2O_5 treatment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
				mgm. K_2O	mgm. P_2O_5	
37	Clover and grass mixture	Very young soil, neighbouring soil 38, hence response to P_2O_5 cannot be expected	No	36.3	16.7	Yes
38	Alfalfa	1931 experiment shows no increase in yield of alfalfa through fertilization with 100, 150 or 200 lbs. of treble superphosphate respectively	No	30.5	20.9	Yes
39	Alfalfa	1931 Treatment — Yield of Hay Check — 6524 lbs. per acre 100 lbs. treble superphosphate — 7164 " " " 250 lbs. treble superphosphate — 7957 " " "	Yes	29.0	14.7	No
40	Sweet clover	Very patchy stand. Representative, sampling impossible. No response to 100 and 200 lbs. per acre could be seen.	No	25.4	11.9	Yes

many years the soil of the slough is very wet in the spring and afterwards puddled so that no crop can grow and remove nutrients. Due to favorable conditions there was no difference in the stand of the whole field in 1931.

34. The discrepancy between field result and Neubauer figure can not be explained.

35. The barley of this experiment was damaged by frost and yielded only very little. Differences of the stand in the field could not be noticed throughout the growing season. A fertilizer experiment with oats on a neighbouring field showed that the soil was sufficiently supplied with available phosphorus for the growth of grain. If we assume this to be the case also on the barley field the Neubauer figure of 6.9 is well in accordance with the field results.

36. Good correspondence between field results and Neubauer figure.

37. Very young soil; natural vegetation had not been killed off completely and competed with clover and grasses, smothering them almost entirely.

38. Good correspondence between field results and Neubauer figure.

39. This is the only field experiment in the Cooking Lake district indicating a deficiency in available P_2O_5. There were no visible differences between the check plot and the fertilized plots. The small increases in yield may be due to unrepresentative sampling.

40. Apparently a correspondence between field results and Neubauer figure.

Other soils; data given in Table VI.

41. Due to the low apparent specific gravity of peat the critical Neubauer figures have to be raised. 100 gms. peat soil represent a greater percentage of the surface soil of one acre than 100 gms. of mineral soil. Taking that into consideration 7 mgm. P_2O_5 indicate a serious deficiency of available P_2O_5, a fact that is confirmed by the results of the fertilizer experiment.

42. This soil was called "gumbo" by the farmer. Since the sample, however, contained 3.5% $CaCO_3$ it seems to be subsoil that has lost its cover by soil drifting, and is as yet too inactive to be able to promote the growth of wheat. Also, the rye in the culture pots did not penetrate the soil with its roots as profusely as in all other pots. Since the soil had been diluted with coarse sand it is not likely that its physical properties are responsible for that. Possibly some toxic agent is the cause for the sterility of this soil.

General Discussion of Neubauer Results: The research reported in this paper has two main objects; first of all to find whether the methods used for the determination of plant available phosphorus are reliable also under Alberta conditions; secondly, whether any relationship can be found between the amount of available plant food in the different soil groups.

Table VI. Field responses to fertilization and Neubauer data.

Other Soils

No.	Crop in 1931	Field Experiment			Field response to P_2O_5 treat-ment	Neubauer figure		Neubauer figure for P_2O_5 conforms field results
						mgm.K_2O	mgm.P_2O_5	
41	Potatoes	1931	Treatment	Yield of Potatoes	Yes	21.7	7.0	Yes
			Check	193 bu. per acre				
			100 lbs. treble superphosphate	253 " " "				
			Increase	60 " " "				
42	Wheat	This sample was taken from a small sterile spot in a fertile black soil field			---	6.2	1.7	Yes

In attempting to get a definite idea regarding the reliability of the Neubauer results it seems to be simplest to compare the number of samples that show correspondence between Neubauer figure and field result and those that do not. These numbers have been counted for the different soil groups individually and for all analyzed samples together. They are calculated on a percentage basis and are given in Table VII.

This summary gives a very favorable picture of the reliability of the Neubauer results under Alberta conditions. In round figures, 4 out of 5 analyses give correct results, inspite of the fact that this method has been designed for Germany while we work here under entirely different climatic and soil conditions. The ratio holds more or less for the individual soil groups too, indicating that the value of the Neubauer method in Alberta is not limited only to certain soil belts, but rather seems applicable to the whole cultivated area of Alberta. The samples analyzed represent soils from the International Boundary to the Peace River district.

It should, of course, not be overlooked that this percentage calculation is only a very rough way of determining the value of the method. It is only a qualitative test. In order to get also quantitative evidence we had to calculate the deviation of the Neubauer figure obtained from the critical Neubauer figure for the given conditions, and to compare this deviation with the size of the increase due to fertilization.

Table VII. Reliability of Neubauer method in Alberta

	Number of samples for which field results for comparison are available	Number and percentage of samples showing correspondence between Neubauer figure for P_2O_5 and field results		Number and percentage of samples showing no correspondence between Neubauer figure for P_2O_5 and field results	
		No.	%	No.	%
Black soils	12	10	83.33	2	16.67
Brown Prairie soils	7	6	85.72	1	14.28
Grey Wooded soils	7	5	71.43	2	28.57
Transitional Wooded soils	9	7	77.78	2	22.22
Other soils	2	2	100.00	-	0.0
Total	37	30	81.08	7	18.92

Such a calculation on the basis of the data reported in this paper will not be attempted because there is too little information as to the actual field response. Only in a few cases are the data based on field experiments that had four or more replications, several of the experiments had only one check and one superphosphate plot, while some of the field experiments used had been carried out a year before the samples were taken. In a number of cases the likeliness of response to the application of phosphatic fertilizers could only be estimated. Although we are perfectly convinced that all the field data given in this paper represent qualitatively the conditions of the different fields, we believe that the quantitative data are not numerous and accurate enough to base an elaborate calculation upon them.

In attempting to find relationships between soil groups and the amount of available plant food we have to realize that the amount of available plant food in the soil in general is so small that one or two good crops taken from the field can reduce it materially. On the other hand any fertilization with commercial fertilizer, barnyard or green manure will raise it. Consequently the amount of available plant food in a soil will usually depend to a great extent on the type of farming. Neubauer himself points out that it is useless to prepare pedologic maps which indicate the amount of available plant food as this amount is subject to great and frequent changes (13). In Alberta, however, where application of any kind of manure has hardly been practiced as yet,

and where the soils are only a comparatively short time under cultivation, some generalizations are justifiable. The data both from Neubauer analyses and from field experiments are used for this purpose.

Black parkland soils are naturally low in available phosphorus. Three of the five high phosphorus figures were obtained from soil fertilized with superphosphate. Potassium is available in sufficient quantities.

Brown prairie soils are very low in available phosphorus, but sufficiently supplied with available potassium.

Grey wooded soils are inclined to be low in available phosphorus and decidedly deficient in available potassium. The leaching that occurs in these soils seems to remove the available potassium more easily than the available phosphorus, as specially shown by the samples of the A_2 horizon (No. 23 and 24).

The transitional wooded soils, which are generally located between the black and the wooded soil belts, might be expected to take also an intermediate position as regards available plant food. This relationship, however, could not be found. The 9 soils investigated are high in available phosphorus and either sufficiently or abundantly supplied with available potassium. This latter fact particularly shows a striking difference from the grey wooded soils, while the high amount of available phosphorus is found in neither the black nor the wooded soils.

Although only one peat soil has been under invest-

igation it seems worth while noticing that it responded both to P_2O_5 and K_2O fertilization, and that the Neubauer figures are in accordance with that. Since peats are generally low in available phosphorus and potassium it is to be expected that a more general cultivation of peats in Alberta will not be started before most of the mineral soils have been cultivated, and this especially because these unfavorable chemical conditions are coupled with very objectionable physical properties.

The Lemmermann Method

Ten of the soil samples used for the Neubauer analysis whose phosphorus requirements were well known were selected and used for testing the Lemmermann method (6,7).

Lemmermann assumes that the ratio of readily soluble phosphorus - measured by its solubility in a weak solvent - to the total amount of soil phosphorus gives us the best indication of the availability of soil phosphorus for plant nutrition.

A soil with comparatively large, or for other reasons difficulty accessible particles may have a high total phosphorus content, but most of it is not available to the plants, while another soil may have a smaller total phosphorus content, but the solubility of its individual particles may be higher. Lemmermann concludes that in this latter case the supply of soluble phosphorus forthcoming during the growing season will be more abundant than in the

first case. This, of course, will only be true within certain limits: in a soil very low in total phosphorus even a very high percentage of solubility would not make enough phosphorus available for the production of a large crop.

The technic of the Lemmermann method consists in determining the total and the 1% citric acid soluble phosphorus, and in calculating the relative solubility, which means the percentage of total phosphorus soluble in citric acid. If this is higher than 25% and the total phosphorus content higher than 25 mgm. P_2O_5 per 100 gms. of soil, Lemmermann assumes that the soil is well supplied with available phosphate. If the relative solubility is between 20 and 25% it is dubious whether the soil contains enough available phosphorus for the production of a good crop or not.

Naturally the same considerations for establishing the critical figures for a given case regarding soil type, climate, and crop that apply for the Neubauer method hold true for this method as well.

Results from the Lemmermann Experiments: Table VIII shows the results of the determination of the phosphatic condition of ten soils according to the Lemmermann method.

The numbers of the soil samples refer to those given in Table I.

Discussion of Lemmermann Results: Using again the original critical figures unchanged the results are very satisfactory. In this case we find 100% correspondence between

Table VIII. Field responses to fertilization and Lemmermann data

Soil Sample	2	5	6	12	14	16	28	30	37	42
Total P_2O_5 Aqua Regia extraction. mgms. of P_2O_5 in 100 gms. of air dry soil	187.8	283.1	198.4	226.8	161.0	152.5	163.6	194.0	222.6	151.4
Citric Acid extraction. mgms. of P_2O_5 in 100 gms. of air dry soil	7.5	100.1	11.2	13.5	55.1	23.2	38.1	38.1	61.3	7.5
Relative solubility	4.0%	37.0%	5.7%	3.8%	34.2%	15.2%	23.4%	19.7%	27.5%	4.9%
Does Lemmermann result indicate response to P_2O_5 fertilization	Yes	No	Yes	Yes	No	Yes	dubious	Yes	No	Yes
Field response to P_2O_5 treatment	Yes	No	Yes	Yes	No	Yes	#	Yes	No	Yes

Yes for legumes, no for grain.

laboratory analyses and field results. The small number of samples analyzed, of course, makes it impossible to draw any definite conclusions as to the value of the method. The great success of this first test makes it, however, advisable to repeat it on a larger scale since wherever the determination of available phosphorus only is required it has the great advantage over the Neubauer method of being much shorter and cheaper.

A serious objection against the Lemmermann method is the use of dilute citric acid as a solvent. If carbonates of calcium and magnesium are present in the soil they will neutralize a part of the citric acid. Therefore the carbonates have to be determined and an equivalent amount of citric acid has to be added in excess to obtain the desired concentration. As the determination may not always be very accurate, this will frequently result in a slight error. Also, the citrates so formed will tend to increase the solvent action of the solution.

There are, also, other substances in the soil that will buffer the citric acid, organic matter being the most important among them. In order to insure reliable results it seems to be necessary to alter the amount of citric acid in such a way as to get the same pH in all the soil suspensions after shaking, since the solving power of the citric acid solution is proportional to its acidity.

Certain soils - apparently due to their high content of ferric salts - have a tendency to decompose citric acid

Laboratory analyses and field results. The small number of samples analyzed, of course, makes it impossible to draw any definite conclusions as to the merits of the methods. The great success of this first trial makes it seem advisable to repeat it on a larger scale since refinements and determination of available phosphorus only is valuable in for its great strength, aside its apparent merits of being much shorter and cheaper.

A serious objection against the [illegible] method is the use of citric acid as a solvent. If carbonates of calcium and magnesium are present in the soil they will neutralize a part of the citric acid. Therefore the carbonates have to be determined and an equivalent amount of citric acid had to be added in excess to obtain the desired concentration. As the determination may not always be very accurate, this will frequently result in a faulty analysis. Also, the citrates so formed will tend to increase the concentration of the solution.

There are, also, other substances in the soil that will modify the citric acid, organic matter being the most important among them. In order to insure reliable results it seems to be necessary to either use more of citric acid of such a way as to get the same pH in all the soil suspensions after shaking, since the solvent power of the citric acid solution is proportional to its acidity.

Certain soils - especially in the black land region of Texas soils - have a tendency to decompose citric acid with into acetone and carbon dioxide (2). It is impossible to subject such soils to the Lemmermann test. Although such cases do not seem to occur very frequently they show that the Lemmermann method cannot be employed universally.

GENERAL DISCUSSION

Limitations of Predicting the Relation of Soil Phosphorus to Crop Plants

In testing soils for "available" or "readily available" phosphorus we expect to find the amount of phosphorus that the crop will be able to absorb from the soil in the following season. This postulate shows us already the first great difficulty. The growth of next year's crop and consequently the absorption of phosphorus is dependent upon a great number of factors: kind of crop, variety, weather, type of soil, physical, chemical and biological condition of the soil, application of other fertilizers, time and method of seeding, occurrence of crop pests and probably a number of other factors. Considering these points it is self-evident that in trying to determine the available phosphorus we can at the best find only approximate figures.

By analyzing the plants (including of course the roots) we can find out the average requirement of phosphorus of the various crops. But this will not tell us whether the

same kind of soil phosphorus is available for all crop plants. Special experiments have been carried out to solve this latter problem and it has been found that some crops can absorb sufficient phosphorus in soils in which others would starve. We would have to determine a different fraction of the soil phosphorus for every individual crop. Fortunately the differences of the form of phosphorus taken up by the plants do not seem to be so very great as far as the usual crop plants are concerned.

Another difficulty arises from the question: How do we have to take the soil sample? The depth of penetration of the roots is very different according not only to the particular crop but also to the type of soil and subsoil and to the climate of the district. In a semi arid country like Western Canada most plants develop roots that extend far below the surface 6 inches. It seems to be dubious whether it is justifiable to use soil samples representing the plow depth only for determining plant food in Alberta as is customary in other more humid regions where the plants feed comparatively close to the surface. And besides we have to consider the different types of root systems. Some plants send their roots down without much branching in the upper layers of the soil, others depend mostly on the surface soil, others again have an intermediate position in this respect. The roots of some plants are very close together, searching for every bit of food in a limited area, while those of others are more dispersed and cover a greater volume of soil.

The roots of many of our crop plants are comparatively far apart in the soil. They can absorb nutrients only when they get into contact with them. It is evident that the movement of the soil solution is a very important factor in plant nutrition. The greater this movement the more likely is every part of the soil solution to get into contact with the roots. That means, the greater the movement of the soil solution the less rich can it be to answer the same feeding requirements. This movement is generally very slow in Alberta soils, and particularly so in the black soils where neither leaching nor upward movement occurs to any great extent. This fact may be the reason that Alberta black soils with high content of available phosphorus according to Wisconsin standards showed marked response to phosphorus fertilization (4).

All these considerations make it evident that even if we find a method that shows us the phosphorus available for a certain crop in a certain soil sample, we have to be very careful in drawing conclusions as to the phosphatic reaction of the field from which the sample has been taken upon the same or other crops.

Summarizing our expectations of a determination of the phosphatic condition of a soil and putting them into the words of the practical farmer we may say: We want to know whether we will have to apply phosphatic fertilizers to a given field, and how much, to insure - average climatic conditions assumed - highest returns in dollars and cents; and we want to obtain this knowledge at the least possible

cost and at a date so early that we may be able to purchase and apply the fertilizer at the most favorable time for this operation, which is in most cases in Alberta shortly before seeding time.

In mentioning the limitations of the methods of determining plant available phosphorus in soil it seems to be necessary to point out that no attempt is made in these methods to determine the phosphatic condition of the soil from a purely scientific point of view. The questions as to which part of the soil phosphorus it is that the plants can use and how they take it up are entirely disregarded. The same is true concerning the availability of phosphorus at different reactions of the soil solution. These problems are exceedingly complicated and the studies devoted to their solution have assisted but little in determining whether a field does or does not need phosphorus fertilization in order to produce a maximum crop. However, it must be the aim of soil science to answer those questions. Only after we understand the interrelationship of the soil, the nutrients and the plants will we be able to determine the phosphatic value of a soil accurately. Up to date the methods for determining available plant food in soils are merely empirical. For practical purposes, however, an empirical result will be very welcome as long as it is sufficiently reliable.

Comparison of Field Experiments with Neubauer and Lemmermann Determinations

The field experiment, however valuable it will be in informing us about the nutrient condition of the soil, will not answer our desires. It is expensive, subject to diseases and the particular weather of the season, it represents only the comparatively small part of the field where it has been conducted and its information comes to us one year too late. Its great advantages should of course not be overlooked. The field experiment is the only experiment that deals with undisturbed natural soil conditions taking all the items into account that influence our crops such as climatic factors, topography, physical and chemical conditions including catalysts and toxins of which we do not know, surface soil, subsoil, drainage, weeds, etc. All these factors influence the plants of the Experimental plots in the same sense and degree as the rest of the field crop, while only a few of these will be allowed to influence the results of laboratory determinations.

Both the Neubauer and the Lemmermann determinations can be available at any convenient date; they can, if the samples are appropriately taken, represent a great part of the field and the expenses are comparatively small; the Lemmermann method being superior to the Neubauer method in this respect.

Owing to its more natural action upon the soil it may be expected that the Neubauer method has a more universal range of adaptation than the Lemmermann method.

With due regard to the limitations of the research reported in this paper resulting especially from the fact that the experiments have been carried out one year only and that but a small number of field experimental results have been available for purpose of comparison, it may be stated that both the Neubauer and the Lemmermann method may be used profitably for the determination of the phosphatic condition of the soils of Alberta.

SUMMARY

(1) The purpose of the work reported in this paper was to find a method for the determination of available phosphorus adapted to Alberta conditions.

(2) Laboratory methods previously used for determining plant available phosphorus in Alberta soils have not proven satisfactory. It is assumed that this is due mainly to the difference of climatic conditions - short summer, long sunshine hours - between Alberta and the regions for which these methods were developed.

(3) Studies reported in this paper consisted of the determination of available phosphorus and potassium by the Neubauer method and of available phosphorus by the Lemmermann method.

(4) For this purpose various soils were collected from different soil belts in Alberta, representing fields from the International Boundary to the Peace River district.

(5) In most cases these samples were taken from fields whose response to phosphorus fertilization was known. Sixty two per cent of the latter showed response to phosphorus fertilization in the field. This percentage is not representative of the whole province, since for

our purpose soils had to be selected which did and did not show deficiency in available phosphorus. The percentage of Alberta soils responding to phosphorus fertilization is considerably higher, as shown in the report of the co-operative fertilizer trials conducted in 1930 throughout the whole province.

(6) Forty two samples were subjected to the Neubauer test, and ten samples were subjected to the Lemmermann test.

(7) Eighty one per cent of the 37 analyses of soils whose field response were known showed correspondence between laboratory analyses and field results in the case of the Neubauer method and in the case of the Lemmermann method all 10 samples analyzed showed correspondence with field results.

(8) The same critical figures indicating the boundary between soils needing and soils not needing phosphorus fertilization as are suggested by Neubauer and Lemmermann for German conditions could be used for Alberta conditions. The lower yields in Alberta should be expected to result in lower critical figures. It seems, however, that the more unfavorable Alberta climate compensates for this factor.

(9) The results of the determinations of available phosphorus in Alberta soils by the Neubauer, as well as by the Lemmermann method, have been very promising. Already we can with reasonable reliability inform an Alberta farmer of the necessity of applying phosphorus fertilizer to his fields.

Further investigations, however, will be necessary if we want to be able to predict the amount of phosphorus fertilizer needed for the production of optimal crops under given conditions.

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REFERENCES

(1) CHRISTENSEN, H. R.
On the occurrence and distribution of Azotobacter chroococcum in different soils.
Exp. Sta. Rec., Vol. 18, pp. 720-721. 1906-1907.

(2) DEAN, L. A. and DEAN, A. L.
Decomposition of citric acid by soil.
Soil Sci. Vol. 28, pp. 281-287. 1929.

(3) DIETZ, R.
Versuche zur Abkürzung des Keimpflanzenverfahrens von Neubauer.
Ernähr. d. Pflanze. Bd. 27, pp. 429-432. 1931.

(4) DOUGHTY, J. L.
Phosphorus studies on Alberta soils.
Sci. Agr. Vol. 12, pp. 43-51. 1931.

(5) GRAY, E. L. and BUCKINGHAM, E. H.
Report of the cooperative fertilizer trials, season of 1930, conducted under the direction of the field crops branch, Department of Agriculture, Edmonton, Alberta.

(6) LEMMERMANN, O.
Die Bestimmungsmethoden des Düngerbedürfnisses des Bodens.
Zeitschr. Pflz. Düng. B. Bd. 4. 1925.

(7) ____________. und FRESENIUS, L.
Über die Bestimmung der relativen Löslichkeit der Bodenphosphorsäure.
Zeitschr. Pflz. Düng. A. Bd. 2, pp. 363-369. 1923.

(8) MITSCHERLICH, E. A.
Über weitere Untersuchungen zum Wirkungsgesetz der Wachstumsfaktoren.
Ernähr. d. Pflanze. Bd. 27, pp. 277-286. 1931.

(9) NEUBAUER, H.
Die Bestimmungsmethoden des Düngerbedürfnisses des Bodens.
Zeitschr. Pflz. Düng. B. Bd. 4, pp. 32-34. 1925.

(10) NEUBAUER, H.
Über die Vertrauenswürdigkeit der Keimpflanzenmethode.
Ernähr. d. Pflanze. Bd. 27, pp. 474-475. 1931.

(11) __________.
Die Keimpflanzenmethode und die neuen chemischen Methoden der Bodenuntersuchung.
Ernähr. d. Pflanze. Bd. 27, pp. 505-511. 1931.

(12) __________.
Die Keimpflanzenmethode nach Neubauer und Schneider.
Handbuch der Pflanzenernährung und Düngerlehre von F. Honcamp. (Julius Springer, Berlin), pp. 882-902. 1931.

(13) __________.
Der Wert von Bodenkarten mit Darstellungen des Nährstoffgehaltesder Böden.
Ernähr. d. Pflanze. Bd. 27, pp. 169-170. 1931.

(14) __________. und SCHNEIDER, W.
Nährstoffanfnahme der Keimpflanzen und ihre Anwendung auf die Bestimmung des Nährstoffgehaltes der Böden.
Zeitschr. Pflz. Düng. A. Bd. 2, pp. 329-362. 1923.

(15) NEWTON, J. D.
Measurements of carbon dioxide evolved from the roots of various crop plants.
Sci. Agr. pp. 268-274. 1924.

(16) NICKLAS, H., POSCHENRIEDER, H. und FREY, A.
Untersuchungen zur Feststellung der Magnesiadüngebedürftigkeit von Böden mittels Aspergillus niger.
Ernähr. d. Pflanze. Bd. 27, pp. 465-470. 1931.

(17) ______________________________.
Die Ausführung der Aspergillusmethode zur Prüfung auf Kali.
Ernähr. d. Pflanze. Bd. 28, pp. 86-88. 1932.

(18) PARKER, F. W.
Carbon dioxide production of plant roots as a factor in the feeding power of plants.
Soil Sci. Vol. 17. pp. 229-247. 1924.

(19) SACKETT, W. G. and STEWART, L. C.
A bacteriological method for determining mineral soil deficiences by use of the soil plaque.
Colorado Agr. Coll. Bull. 375. 1931.

(20) SCHARRER, K.
Aufgaben und Forschungsergebnisse der modernen Agrikulturchemie auf dem Gebiete der Ernährung der höheren Kulturpflanzen.
Ernähr. d. Pflanze. Bd. 28, pp. 6-11. 1932.

(21) SPURWAY, C. H.
A test for water soluble phosphorus in field soils.
Mich. St. Tech. Bull. 101. 1929.

(22) TRUOG, E.
The determination of readily available phosphorus of soils.
J.A.S.A. Vol. 22, pp. 874-882. 1930.

(23) WHEETING, L. C.
A study of methods for the determination of the available potassium of soils.
Soil Sci. Vol. 29, pp. 1-21. 1930.

(24) WILEY, R. C. and GORDON, N. E.
Availability of adsorbed phosphorus.
Soil Sci. Vol. 15, pp. 371-373. 1923.

(25) WYATT, F. A. and NEWTON, J. D.
Wooded soils and their management.
Univ. of Alberta, Bull. No. 21. 1932.

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